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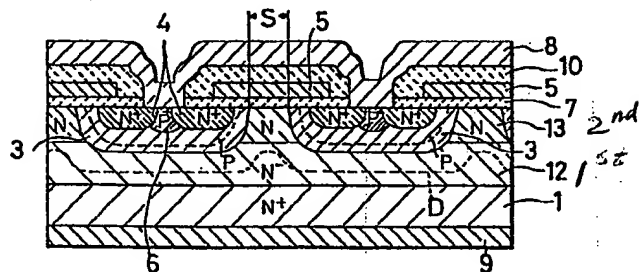
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54 MOSFET with high density of integration and low on resistance.

57 A vertical type MOSFET having a high degree of integration and a low ON resistance is shown. This device is formed so that the drain region has low resistivity part between well regions and the high resistivity part with which the bottoms of the well regions are in contact. Thereby provided is the MOSFET which has low ON resistance and a high breakdown voltage in spite of its high degree integration.

FIG. 2



TITLE OF THE INVENTION

MOSFET WITH HIGH DENSITY OF INTEGRATION AND LOW ON RESISTANCE

BACKGROUND OF THE INVENTION

This invention is related to a vertical type MOS field effect transistor (MOSFET) with a high density of integration and a low ON resistance.

With reference to a cross-sectional view in FIG. 1, the configuration of an N-channel vertical type MOSFET as a prior art and some of the problems with it are described below.

This MOSFET consists of an N-type low resistivity drain region 1 ( $N^+$  semiconductor substrate), a high resistivity drain region 2 ( $N^-$  layer) which lies above it, P-type well regions 3 which are located in the upper half of this drain layer 2 and isolated from each other, and low resistivity N-type source regions 4 ( $N^+$  regions) which lie within these well regions. The well region 3 performs the function of channel respectively.

The well regions 3 are separated by a distance S. In the centers of the well regions 3 there are P-type low resistivity well contact regions 6 ( $P^+$  regions) which are in contact with the well regions 3. In addition, all of these regions except for the parts of the source regions 4 and the contact regions 6 in contact with a source electrodes 8 are covered by the silicon dioxide film 7. Formed on top of this silicon dioxide film 7 is a multi-crystalline silicon gate electrode 5 which spans the gaps between the neighboring well regions 3. This gate electrode, in turn, is covered by an insulation film 10 made of a material such as phosphorus glass.

The source electrode 8 covers this insulation film 10, which is deposited on top of the other layers by vacuum deposition and which contacts the source regions 4 and the well contact regions 6. Also, on the bottom surface of the drain region 1 a metallic drain electrode 9 is deposited by a similar process of vacuum deposition and makes contact with the drain substrate 1.

In FIG. 1, dotted line D indicates the limit of the depletion layer that is produced when the PN junction between the source and drain of this vertical type FET is reversely biased.

When a sufficient voltage is applied to the gate electrode

1 5, a channel region is formed in the well regions which lie below  
the gate electrode 5. Then when a voltage is applied to the  
drain electrode 9 with respect to the source electrode 8, an  
electric current flows from the drain electrode 9 to the drain  
5 region 2 through the drain substrate 1 and passes through the  
channel layer to the source regions 4 and the source electrode 8.

A MOSFET with this kind of configuration has really a wider  
area over which current is drawn than a so-called horizontal-type  
MOSFET, which has the source and drain electrodes on the same  
10 surface, making it more suitable as an element in applications  
where a large electric current must be handled. Also, sometimes  
the well regions 3 and source regions 4 are formed by double  
diffusion, with the gate electrode 5 as a mask, and because the  
concentration of impurities can be accurately controlled, the  
15 threshold in the operation of the MOSFET is accurate, without  
fluctuations.

However, in this kind of prior art vertical type MOSFET, a  
current flows in the high resistivity drain region confined  
between the well regions 3, so that there is a limit to how far  
20 the resistance during the time when a current is flowing between  
the source and the drain (to be referred to as ON resistance) can  
be reduced. That is to say, when the resistivity of the high  
resistivity drain region is reduced, a large electric field is  
produced at the junctions with the well regions 3, and the  
25 breakdown voltage between the source and the drain decreases.  
This causes the defect that there is a limit to how far the  
resistivity of this drain region 2 can be reduced.

Meanwhile, within the limit of the effective gate width, it  
is conceivable that the unit cell density could be increased to  
30 lower the ON resistance, but this would cause the region between  
the two well regions, labeled S in FIG. 1, to be narrowed still  
further, reducing the area through which the current can flow so  
that there would be no net reduction in the ON resistance.

Whether this ON resistance is large or small is a very  
35 important problem which affects the amount of heat given off by

high S  
layer  
only

each semiconductor element, the limit to the density of elements in the circuit imposed by this heat, the power consumption and the reliability. In particular, in an element designed to handle a large electric current it is important to reduce the ON resistance as much as possible.

#### SUMMARY OF THE INVENTION

An object of the invention is to provide a vertical-type MOSFET which has a high density and a low ON resistance.

Another object of the invention is to provide vertical-type MOSFET which has a high breakdown voltage in spite of its low ON resistance.

These and other objects and advantages and effects are accomplished by provision of a transistor in which the drain region between the well regions is a region with low resistivity, in order to reduce the resistance. In addition, between this layer and the semiconductor substrate there is another layer with a higher resistivity than that of the semiconductor substrate; and the well regions are extended to this layer.

#### BREIF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view showing a prior art vertical-type N-channel MOSFET.

FIG. 2 is a cross-sectional view showing a first embodiment according to the invention.

FIGS. 3(a) through (g) depict steps in the process by which the transistor in FIG. 2 is produced.

FIG. 4 is a cross-sectional view showing a second embodiment of vertical-type MOSFET according to the invention.

FIGS. 5(a) and (b) depict steps in the process by which the transistor shown in FIG. 4 is produced.

#### DETAILED DESCRIPTION OF THE PERFERRED EMBODIMENTS

Referring now paticularly to FIG. 2, a first embodiment of a vetical-type MOSFET in accordance with the invention is shown. Those letters and numerals which also appear in FIG. 1 have the same meanings in both figures. Consequently, it is dispensed with to describe them again here. The interval S between the

1 well regions 3 is only half as great in FIG. 2 as in FIG. 1, but  
its ON resistance is nevertheless lower due to the configuration  
of the invention described detailedly hereinbelow.

First, described are the differences in configuration  
5 between the present MOSFET and the conventional type shown in  
FIG. 1. As can be seen in FIG. 2, above the drain substrate 1,  
which serves as a  $N^+$  semiconductor substrate, there is a high  
resistivity drain region 12 (an  $N^-$  region), which has a higher  
resistivity than this substrate, as the first drain region.  
10 Above it, as the second drain region, there is a low resistivity  
drain region 13 (an N region), with lower resistivity than this  
high resistivity drain region 12. Then, the well regions 3 are  
formed so that they penetrate more deeply than the low  
resistivity drain region 13, extending to the high resistivity  
15 region 12.

In FIG. 2, in the high resistivity drain region 12 and in  
the well regions 3, indicated with the dotted lines D are the  
limits of the depletion layer that is produced when the PN  
junction between the source and drain of this vertical type  
20 MOSFET is reversely biased.

That is to say, when a voltage is applied between the drain  
electrode and the source electrode, a reverse bias is created at  
the PN junction between the high resistivity drain region 12 and  
the well regions 3, and between the low resistivity drain region  
25 13 and the well regions 3, thereby causing the depletion layers  
corresponding to each well regions 3 to expand and link up with  
each other and producing the situation shown in FIG. 2.  
Consequently, in this case the breakdown voltage is primarily  
determined in the lower parts of the well regions 3.

30 Next, a production process of the first embodiment of a  
MOSFET having the configuration described above will be  
described.

A specific example of such a production process is shown in  
FIG. 3 (a) through (g).

35 The first step is to prepare the low resistivity drain

only  
reverse  
bias state

not bottom

substrate 1 (the  $N^+$  substrate) which is made up of N-type silicon monocrystalline having a donor impurity concentration  $N_D$  of about  $1 \times 10^{18}$  atoms/cm<sup>3</sup>. Then, in this example, phosphene ( $PH_3$ ) is introduced as an impurity gas and on the surface of this substrate 1 the high resistivity drain region ( $N^-$  region) 12 having an  $N_D$  on the order of  $2 \times 10^{15}$  atoms/cm<sup>3</sup> and a thickness of about  $10 \mu m$  is epitaxially grown. After that the flow rate of phosphene is changed to cause epitaxial growth of the low resistivity drain region (N region) 13, having an  $N_D$  on the order of  $5 \times 10^{15}$  atoms/cm<sup>3</sup> and a thickness of about  $4 \mu m$ , on top of this epitaxially grown high resistivity drain region 12. The structure which results after these steps are completed is shown in FIG. 3(a).

The next step is to grow a silicon dioxide film 7 on top of the epitaxially grown low resistivity drain region 13 by means of thermal oxidation to a thickness of about 1000 Å. On the surface of this, silicon polycrystalline 5, to be used as the gate electrode, is grown to a thickness of about 4000 Å by the CVD method. When this step has been completed the structure is as shown in the cross-sectional view in FIG. 3 (b).

The next step is to selectively remove this silicon polycrystalline layer 5 by photographic etching at the locations corresponding to the well regions 3. Then boron ions ( $B^+$ ) are injected to a concentration of about  $5 \times 10^{13}$  atoms/cm<sup>2</sup> by the ion implantation method. After that, the partly completed transistor is heat treated at about 1100 °C for 24 hours, causing simultaneous annealing and diffusion, thus producing the 4 to 6  $\mu m$ -thick well regions 3. After these steps have completed the structure is as shown in the cross-sectional view in FIG. 3 (c).

The next step is to cover all areas not corresponding to what will become the well contact regions with the photo resist shown by the dotted lines 15; then, with these as masks, boron ions ( $B^+$ ) are injected to a concentration of about  $5 \times 10^{15}$  atoms/cm<sup>2</sup> by the ion implantation. When these steps have been completed, the structure is as shown in the cross-sectional view

1 in FIG. 3(d). The regions where boron ions have been injected are labeled 6a.

5 The next step is to remove the above-mentioned photoresist 15. Then the regions which are to become the well contact regions are covered by the photoresist 15 indicated by the dotted lines 15; with these as masks, phosphorus ions ( $P^+$ ) are injected to a concentration of about  $5 \times 10^{15}$  atoms/cm<sup>2</sup> by the ion implantation. When these steps have been completed the structure is as shown in the cross-sectional view in FIG. 3(e). The regions where the phosphorus ions have been injected are labeled 4a. The phosphorus ions also enter the silicon polycrystalline 5.

15 The next step is to remove the above-mentioned photoresist 15. Then the electrically insulating film 10 is formed to a thickness of about 7000Å, of phosphorus glass with a molar concentration ratio of about 3%, by the CVD method. Then the partially completed transistor is heat treated in nitrogen at about 1050°C, causing source regions 4 and well contact regions 6 to diffuse until they are about 1μm deep, simultaneously. When 20 these steps have been completed the structure is as shown in the cross-sectional view in FIG. 3(f).

25 The next step is to form the contact for the gate electrodes, the common contact for the well regions 3 and the source region 4. To do this, windows are opened by etching and aluminum is vacuum-deposited on the surface to a thickness of about 1.5μm to form the source electrode 8 and the leading-out port for the gate electrode (not shown in Fig. 3(g)).

30 Then, the bottom of the drain substrate 1 is covered by a 1μm-thick coating of aluminum by vacuum deposition; then the bottom and the deposited coating are alloyed together at about 450°C to form the drain electrode 9. When this step has been completed the structure is as shown in the cross-sectional view in FIG. 3(g).

35 Thus, through the above process, the vertical type MOSFET structure shown in FIG. 2 can be produced.

1 FIG. 4 shows a second embodiment of a transistor in  
accordance with the present invention. In this figure, those  
labels which are the same as labels used in FIG. 1 and FIG. 2  
have the same meanings.

5 The transistor shown in FIG. 4 differs from the transistor  
shown in FIG. 2 in that it has the high-density N type ( $N^+$ )  
buried regions 11 which span the boundary between the drain  
substrate 1 and the high resistivity drain region 12, which is  
the first drain region. These buried regions 11 are located  
0 between and outside of the well regions 3, corresponding to the  
low resistivity drain regions 13 which are the second drain  
regions.

In this case the depletion layer formed by a bias between  
the source electrode 8 and the drain electrode 9 is as shown by  
5 the dotted lines D. The size which the buried regions 11 can  
have is restricted by the condition that they must not contact  
the depletion layer. This condition prevents the buried regions  
11 from causing a reduction in the breakdown voltage. In the  
embodiment shown here the size of the buried regions 11 can be  
10 controlled freely by varying their pattern and the amount of  
diffusion during the production process.

Thus, in the embodiment shown here, because of the presence  
of the buried regions 11, the electrical resistance of the pass  
through which electric current flows is decreased. Consequently,  
25 compared to the transistor shown in FIG. 2, the ON resistance is  
decreased even further.

~~Next~~, an example of production process by which the vertical  
type FET containing these buried regions can be produced will be  
described.

30 FIGS. 5(a) and (b) show a part of this production process.  
Since the remainder of the production process after the step  
shown in FIG. 5(b) coincides with the steps shown in FIGS. 3(b)  
through 3(g), the description are omitted here. Only those steps  
which differ from the process explained above with reference to  
35 FIG. 3 are described here.



1       The first step is to form the silicon dioxide film 14, about  
1  $\mu\text{m}$  thick, by thermal oxidation on the surface of the low  
resistivity drain substrate 1 which is formed from N-type silicon  
monocrystalline having a donor impurity concentration  $N_D$  of about  
5  $1 \times 10^{18}$  atoms/cm<sup>3</sup>. Next, this silicon dioxide film 14 is  
selectively removed by photographic etching at the locations  
corresponding to where the buried regions 11 are to be formed.  
Then arsenic ions ( $\text{As}^+$ ) are injected to a concentration of about  
1  $1 \times 10^{16}$  ions/cm<sup>2</sup> by the ion implantation. When these steps have  
10 been completed, the structure is as shown in the cross-sectional  
view in FIG. 5(a). The regions where the arsenic ions have been  
injected are labeled 11a.

The next step is annealing, after which the silicon dioxide  
film 14 is removed. Then the high resistivity drain region 12  
15 having an  $N_D$  on the order of  $2 \times 10^{15}$  atoms/cm<sup>3</sup> and a thickness of  
about  $10 \mu\text{m}$  is grown epitaxially, for example, by introducing  
phosphene. Then the flow of phosphene is changed to grow the low  
resistivity drain region 13 having an  $N_D$  on the order of  $5 \times 10^{15}$   
atoms/cm<sup>3</sup> and a thickness of about  $4 \mu\text{m}$ . At the same time, the  
20 buried regions 11 are formed by diffusion. When these steps have  
been completed, the structure is as shown in the cross-sectional  
view in FIG. 5(b).

The following steps are the same as those explained with  
reference to FIGS. 3 (b) through (g), eventually resulting in the  
25 vertical-type MOSFET having the structure shown in FIG. 4. The  
following are specific examples of the dimensions and impurity  
concentrations which such a transistor might have. The  
thicknesses of the  $N^-$  regions 12 and the N region 13 are  $10 \mu\text{m}$   
and  $4 \mu\text{m}$ , respectively, and the width of the well regions 3 is 30  
30  $\mu\text{m}$ . The distance S between the well regions 3 is  $5 \mu\text{m}$ , about  
half of the corresponding distance in conventional types of  
MOSFET. The impurity concentrations of the  $N^+$  region 1, the  $N^-$   
region 12 and the N region 13 are  $1 \times 10^{18}$ ,  $2 \times 10^{15}$  and  $5 \times 10^{15}$   
atoms/cm<sup>3</sup>, respectively.

35       The well regions 3 penetrate about  $1 \mu\text{m}$  into the high-

1 resistivity drain region 12, which is the first drain region.

When a voltage is applied between the source and the drain of an MOSFET having the structure described above, then, within the high resistivity drain region 12, the depletion layers are  
5 joined or link up with each other in the low resistivity drain regions 13 while the voltage rises to approximately 30 V, and expand into the part of the first drain region 12 just below the low resistivity drain regions 13. In this case, as in conventional types of transistor, the breakdown voltage is  
0 essentially determined in the lower parts of the well regions 3, and it comes out to be about 150V. Moreover, the ON resistance has been reduced to 1.25 ohm per square millimeter, even though the distance S between the well regions 3 has been reduced to only about half of what it was in conventional transistors.  
5 Also, by reducing the distance S between the well regions 3 to about half of what it was before, the unit cell density has been increased by about 25%.

Incidentally in the conventional MOSFET shown in FIG. 1, if the impurity concentration  $N_D$  in the high resistivity drain  
0 region 2 is taken to be on the order of  $2 \times 10^{15}$  atoms/cm<sup>3</sup>, the thickness of the region 2 to be about  $14 \mu\text{m}$ , the well regions 3 to be  $30 \mu\text{m}$  wide and their diffusion has penetrated to a depth of  $5 \mu\text{m}$ , and if the distance S between the well regions 3 is taken to be  $10 \mu\text{m}$ , then breakdown voltage of about 150V is obtained,  
5 but the ON resistance is rather high, 1.5 ohms per square millimeter.

The practical examples as embodiments of the invention that have been given here are all N channel vertical-type MOSFETs, but it is clear that the N channel MOSFETs can be replaced by P  
0 channel MOSFETs in the above description. Also, the drain region has been split into two parts, a high resistivity region and a low resistivity region, but it is not necessary that it be split into only two parts; it could also be split into three or four  
parts. } 0 0

5 The production processes which have been described in giving

1 practical examples of how this invention could be used in  
transistors has involved the use of the ion implantation but it  
is possible to not use this method and to use, for example, the  
CVD method or the PVD method instead.

5 The values of resistivity given for the semiconductor layers  
in the above embodiments are merely examples; in a particular set  
of circumstances, different values could be used. The usefulness  
of this invention is not limited to the case in which the values  
given here are used.

10 As can be understood from the above description, since, in  
this invention, the drain region is divided into two parts, a  
high resistivity region and a low resistivity region, and since  
the low resistivity region is positioned between adjacent ones of  
the well regions, then even if the distance between the well  
15 regions is set on a small order, the ON resistance does not  
increase to an excessive value. In addition, since the bottoms  
of the well regions penetrate into the high resistivity region,  
there is no reduction in the breakdown voltage of the MOSFET, so  
that the unit cell density can be made high.

20 The effect of reducing the overall ON resistance is  
especially important in reducing the heating and power  
consumption of transistors to be used as elements in circuits  
which handle a large electric current.

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1 What is claimed is:

1. A MOSFET with a high density of integration and a low ON resistance comprising:

- 5 a semiconductor substrate of a first conductivity type;
- a first drain region of said first conductivity type formed on top of said semiconductor substrate;
- a second drain region of said first conductivity type formed on top of said first drain region;
- 10 said second drain region has a lower resistivity than said first drain region;
- well regions of the second conductivity type opposite to said first conductivity type;
- said well region being adjacent to said second drain region and in contact with said first drain region at the bottom
- 15 portions thereof;
- source regions inside said well regions;
- a drain electrode formed on the bottom surface of said semiconductor substrate;
- gate electrodes formed through electrically insulating
- 20 films on top of channels which are formed by the said well regions; and
- at least one source electrode being in electrical contact with said source regions.

25 2. A MOSFET of claim 1, wherein said gate electrode spans said second drain region between adjacent ones of said well regions.

3. A MOSFET of claim 2, wherein said semiconductor substrate having a higher conductivity than that of said first drain region.

30 4. A MOSFET of claim 3, wherein the distance between adjacent ones of said well regions is at least less than 5  $\mu$ m.

5. A MOSFET of claim 3, further comprising well contact regions of said second conductivity type provided in the centers of said well regions and being in contact with said well regions

35 and said source electrodes.

1        6. A MOSFET of claim 1, further comprising low resistivity  
buried regions of said first conductivity type which is located  
at the boundary between said substrate and said first drain  
region and between adjacent ones of said well region.

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[illegible][illegible]

FIG. 3(a)

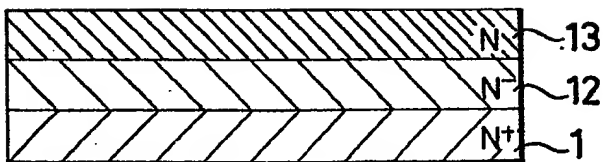


FIG. 3(b)

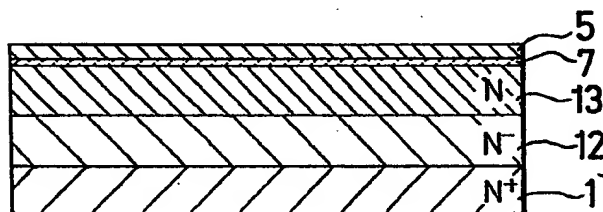


FIG. 3(c)

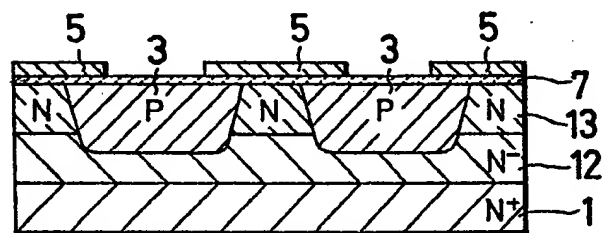
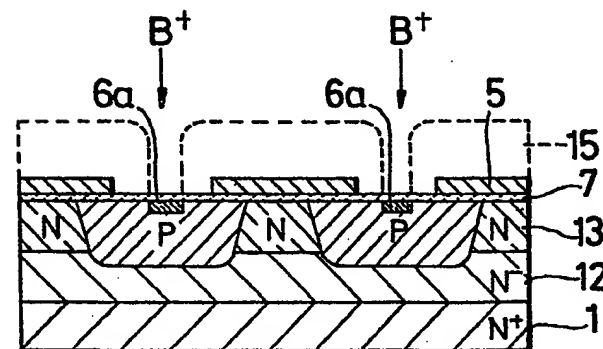


FIG. 3(d)



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FIG. 3(e)

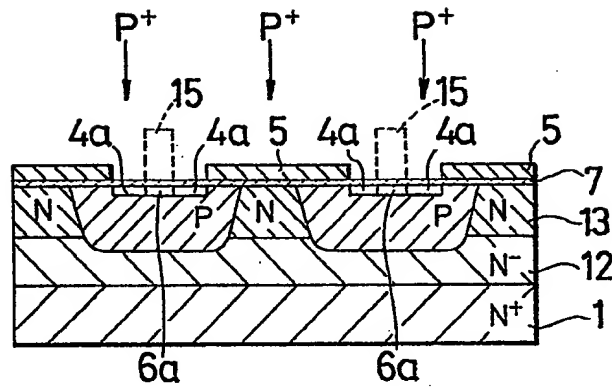


FIG. 3(f)

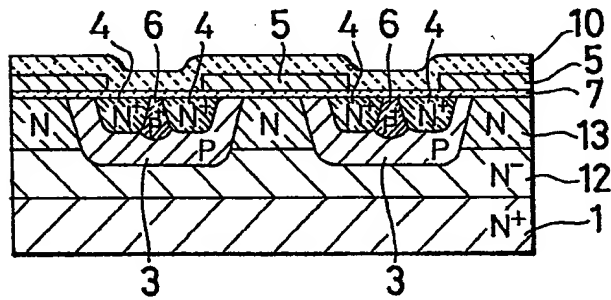
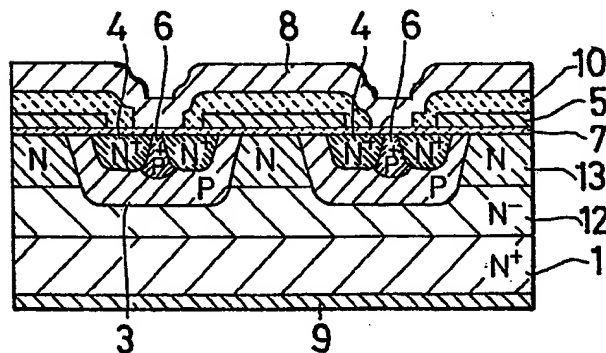


FIG. 3(g)





[illegible]

A cross-sectional view of a semiconductor device during an arsenic ion implantation process. Five arrows labeled  $As^+$  point downwards towards the device. The device consists of a substrate 11a, which is an N<sup>+</sup> type region. A layer 14 is deposited on top of the substrate. The layer 14 is shown in two separate rectangular blocks, with gaps between them. The substrate 11a is shown as a hatched region. The layer 14 is shown as a cross-hatched region.

A cross-sectional diagram of a semiconductor device. The structure consists of several layers. The top layer is labeled 13 and has a diagonal hatching pattern. Below it is a layer labeled 12, which contains a region labeled  $N^-$ . Below layer 12 is a layer labeled 11, which contains a region labeled  $N^+$ . The bottom layer is labeled 1 and has a diagonal hatching pattern. On the left side, there is a region labeled  $p^+$  with a cross-hatching pattern. The regions  $N^-$  and  $N^+$  are separated by a vertical boundary. The  $N^+$  region contains a small circular feature with a cross-hatching pattern.